APPENDIX WQ-2 – Lake Tahoe Basin Stream Water Quality: Sediment and Nutrient Loads in Ten Regularly Monitored Streams

Suspended Sediment and Fine Particles

Relevance – Suspended sediment (SS) is of concern for several reasons: 1) decreased visibility resulting from the suspension of fine particles affects lake transparency and stream clarity, and if it is too severe it can interfere with gill function and filter feeding of aquatic biota; 2) abnormal deposition and build-up of coarse sized sediment on stream beds and in shallow nearshore waters can degrade/destroy fish, macroinvertebrate, and aquatic plant habitat; (3) phosphorus and other compounds that affect water quality are commonly associated with soil and are transported along with sediment; and (4) excessive sediment can serve as an indicator for land disturbance and excessive erosion. Fine sediment particles less than 16 microns in diameter (PSD) have been shown to play an important role in the clarity of Lake Tahoe.[1,2] Consequently, the Lake Tahoe Total Maximum Daily Load (TMDL) has stressed the importance of controlling SS and PSD load to the Lake and documenting success in related management activities.[3,4]

Status – For water year 2010, the yearly SS loads from the ten regularly monitored streams ranged from 2 metric tonnes per year (MT/yr) at Logan House Creek to 3,127 MT/yr at Blackwood Creek (Figures 1-4). The average yearly SS load from all ten streams was 765 MT/yr. The yearly PSD loads from the ten regularly monitored streams ranged from 0.002 x 10^{18} particles per year (particles/yr) at Logan House Creek to 8.02 x 10^{18} particles/yr at the Upper Truckee River for water year (WY) 2010. The average PSD load in WY 2010 was 2.45 x 10^{18} particles/yr. Loads of SS and PSD in 2010 were generally lower in the five Nevada streams than in the five California streams. This is consistent with the finding that a majority of the inflow in 2010 came from the California streams.

Trends – Analysis of trends in hydrology/water quality data can be influenced by the "signal to noise" ratio. In this case the "signal" of interest is the effect of land-use changes and watershed restoration, while the "noise" represents the natural variability in yearly precipitation, rain versus snow, timing of snowmelt and other meteorological factors outside human control, and variability due to errors associated with sampling and laboratory analyses. In the Lake Tahoe Basin, the signal to noise ratio is affected by the high variability in yearly meteorology (i.e. the natural variability in the occurrence of very wet, very dry, and "average" years of precipitation and runoff).

Water years 1993 through 2010 is the period of focus for the analysis of trends, because monitoring at the tenth stream began in WY 1993. The methods used to calculate loads also were the same for all streams starting in WY 1993. Between WY 1993-2010, the yearly SS loads ranged from 0.43 MT/yr at Logan House Creek in WY 2009, to 22,315 MT/yr at Blackwood Creek in WY 1997 (Figures 1 and 2).

The averages yearly SS loads in the individual LTIMP streams over the 18-year period of record ranged from 8 to 4,570 MT/yr (Table 1). The Five California streams accounted for 88 percent of the SS load from all ten streams combined for WY1993-2010, largely as a result of much higher inflows.

Table 1. Average yearly suspended sediment loads from water years 1993 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average year suspended sediment load (Metric Tons/year)	Percent contribution
Blackwood,	4,570	35%
Upper Truckee	3,094	23%
Ward	2,431	18%
Third	1,205	9%
General	753	6%
Trout	739	6%
Incline	372	3%
Edgewood	40	<1%
Glenbrook	30	<1%
Logan House	8	<1%

An examination of SS data collected prior to WY 1993 shows that the Upper Truckee River and Blackwood Creek were major contributors of SS loads to Lake Tahoe. Blackwood Creek yearly SS loads exceeded the Upper Truckee River in 12 of 30 years. However, loads from Blackwood Creek were much higher during years with extreme rain-on-snow events (WY 1997 and 2006) and in WY 1982, a high flow year. The WY in which the SS load peaks occurred differed between the two streams. While yearly inflow from the Upper Truckee River was always greater than Blackwood Creek, the yearly flow-weighted concentration of SS in Blackwood Creek was typically much higher. Trout Creek was a less important contributor of total SS load at only six percent of the combined stream SS loads, despite its South Shore location. The SS yearly loading data indicate that the steep and wet West Shore watersheds (Blackwood and Ward creeks) are subject to erosion and sediment generation, despite their relatively limited development. Of the five Nevada streams, only Third Creek was a substantial source of SS load, but primarily during water years 1991-1995. SS load from Third Creek has been low since the mid-1990s.

Between water years 2002-2010, the yearly loads of fine particles[5] that are less than 16 microns in diameter (PSD), and of high concern for their impacts to Lake Tahoe transparency, ranged from a minimum of 0.0008×10^{18} particles/yr at Logan House Creek in WY 2008, to a maximum of 40.10×10^{18} particles/yr at Upper Truckee River in WY 2006 (Figures 3 and 4). All ten monitored streams had peak PSD loads in WY 2006.

Average yearly loading of PSD over the nine-year period of record ranged by three orders of magnitude or 1000-fold from 0.009×10^{18} to 11.03×10^{18} particles/yr (Table 2).

Table 2. Average yearly fine particle loads from WY 2002 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average yearly load of fine particles < 16 microns (Number of particles/year)	Percent contribution
Upper Truckee	11.03×10^{18}	44%
Blackwood	4.65×10^{18}	19%
Trout	3.67×10^{18}	15%
Ward	2.21×10^{18}	9%
General	0.97×10^{18}	4%
Third	0.82×10^{18}	3%
Incline	0.81×10^{18}	3%
Edgewood	0.44×10^{18}	2%
Glenbrook	0.18×10^{18}	1%
Logan House	0.009×10^{18}	<1%

The rank order of streams in terms of the average yearly PSD load differs from that of the average yearly SS load, although the periods for which data are available also differ. The Upper Truckee River is the greatest contributor with regard to PSD load at more than 40 percent; Blackwood Creek, while still important (19 percent), is less so compared to its SS load. The contribution of Trout Creek was elevated for PSD compared to SS load. The percent contribution of Trout to PSD load was almost three times that for SS (15 percent and six percent, respectively), and Trout Creek was the third largest contributor of PSD, compared to the sixth largest contributor for SS. Again, the five California streams were the most substantial contributors to yearly PSD load, accounting for 91 percent of the loading from all ten streams.

Confidence – There is high confidence in the reliability of the data used to calculate yearly loads as the data collection consistently followed national field monitoring protocols established by the U.S. Geological Survey for stream monitoring.[6,7] All field and laboratory data are subject to extensive quality assurance requirements.[8] A total of 20-35 individual samples are collected each WY from each of the ten streams. This sampling frequency is considered sufficient to sample during different inflow conditions observed during the WY. The stream monitoring program focuses on both event-based conditions (large runoff events associated with rainfall and snowmelt) and baseline conditions (low inflow during summer when precipitation is negligible). The analytical methods for measuring sediment, fine particles, and nutrients have been developed and customized for use in aquatic systems where concentrations can be extremely low.[9]

Human and Environmental Drivers – The Lake Tahoe TMDL[1] found that on average, and over the period 1994-2004, the yearly load of SS from all sources was 29,600 metric tonnes (1 MT = 1000 kg or 2,205 lbs), with about 60 percent of the SS load coming from non-urban upland runoff and stream channel erosion. In contrast, the total number of fine particles (<16 µm) delivered by all tributaries to Lake Tahoe was 13 percent of the total load from all sources. Urban landscapes in the Tahoe Basin produce proportionately less total suspended sediment loads, but proportionately larger loads of fine particles, due to anthropogenic generation and mobilization.

Monitoring Approach – The Lake Tahoe interagency stream monitoring program (LTIMP) was developed in 1979 to provide a Basin-wide evaluation of sediment and nutrient inputs from streams to Lake Tahoe and to support research efforts to better understand the drivers affecting the clarity of Lake Tahoe. Ten streams have been monitored since the early 1990s; five in California (Upper Truckee River and Trout, General, Blackwood and Ward creeks) and five in Nevada (Third, Incline, Glenbrook, Logan House and Edgewood creeks). Six of these streams have been monitored since WY 1980: Upper Truckee River, and Trout, General, Blackwood, Ward, and Third creeks. Some of the ten streams have had multiple monitoring stations along the tributary and all have primary monitoring stations at or near the point of stream discharge to Lake Tahoe. A total of 20-35 individual samples are collected each WY from each of the monitoring stations. The ten primary stations allow for the evaluation of the cumulative conditions within the watershed and represent the inputs of SS and nutrients into Lake Tahoe. U.S. Geological Survey gauging stations are located at each of the monitoring stations, where inflow (stream discharge) measurements are completed and continuous inflow is calculated. Other water quality-related constituents regularly monitored include water and air temperature, pH, specific conductance, and dissolved oxygen. Fine particle monitoring began in 2002 in support of the Lake Tahoe TMDL.

Monitoring Partners – U.S. Geological Survey –Nevada and California Water Science Centers, University of California at Davis – Tahoe Environmental Research Center, Tahoe Regional Planning Agency, and U.S. Forest Service – Lake Tahoe Basin Management Unit.

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1. California Regional Water Quality Control Board, Lahontan Region, and Nevada Division of Environmental Protection, June 2010, Lake Tahoe Total Maximum Daily Load Technical Report.

2. Swift, T.J., J. Perez-Losada, S.G. Schladow, J.E. Reuter, A.D. Jassby and C.R. Goldman. 2006. Water clarity modeling in Lake Tahoe: Linking suspended matter characteristics to Secchi depth. Aquatic Sciences. 68:1-15.

3. Lahontan and NDEP, 2008. Integrated Water Quality Management Strategy Project Report v1.0. 2008. California Regional Water Quality Control Board, Lahontan Region, Nevada Division of Environmental Protection. 108 p.

4. Lahontan and NDEP, 2009, Pollutant Load Reduction Model (PLRM) – Model Development Document. Prepared for California Regional Water Quality Control Board, Lahontan Region, US Army, Corps of Engineers and Southern Nevada Public Lands Management Act. Prepared by Northwest Hydraulic Consultants Inc., Geosyntec Consultants, Inc. and2NDNATURE. 95 p. plus appendices.

5. This data is part of Mr. Dan Nover's Ph.D. dissertation study. University of California, Davis – Tahoe Environmental Research Center. PSD analysis has been done by TERC since 2002 on samples collected by LTIMP. PSD is not part of the list of analyses for LTIMP.

6. U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at http://pubs.water.usgs.gov/twri9A.

7. Rowe, T.G., Saleh, D. K., Watkins, S. A., and Kratzer, C. R., 2002, Streamflow and water-quality data for selected watersheds in the Lake Tahoe Basin, California and Nevada, through September 1998: U.S. Geological Survey Water-Resources Investigations Report 02-4030, 118 p., available online at http://pubs.er.usgs.gov/usgspubs/wri/wri024030.

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9. Goldman, C., Schladow, G., Reuter, J., Hammel, T., and Liston, A, 2009, Lake Tahoe Interagency Monitoring Program: Quality Assurance Manual: Tahoe Environmental Research Center, Univ. California, Davis, 48 p.

Additional Information And References:
The following are examples of additional scientific papers, technical reports and agency report that utilize LTIMP data for sediment and/or fine particles.

- A. Rabidoux. 2005. Spatial and Temporal Distribution of Fine Particles and Elemental Concentrations in Suspended Sediments in Lake Tahoe streams, California-Nevada. M.S. Thesis, University of California, Davis.

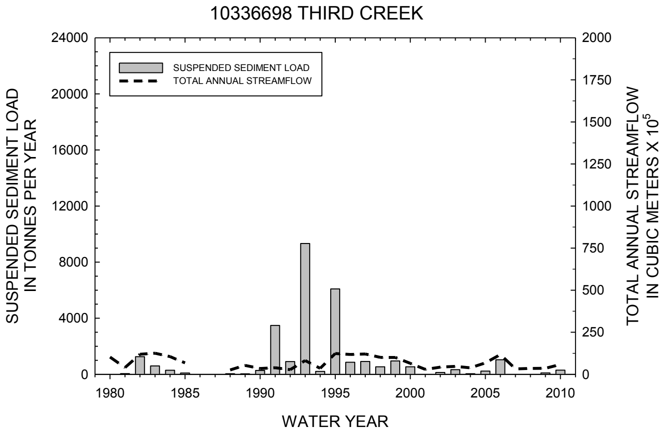
- A. Stubblefield. 2002. Spatial and Temporal Dynamics of Watershed Sediment Delivery, Lake Tahoe. Ph.D. Dissertation. University of California, Davis.

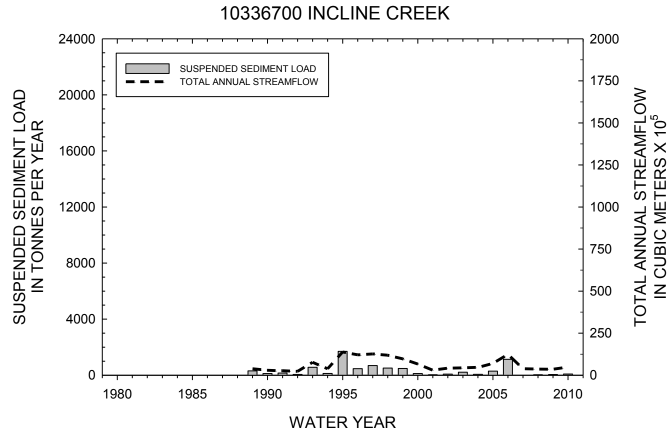
- A. Stubblefield, J. Reuter, R. Dahlgren and C. Goldman. 2007. Use of Turbidometry to Characterize Suspended Sediment and Phosphorus Fluxes in the Lake Tahoe Basin, California, USA. Hydrological Processes 21:281-291.

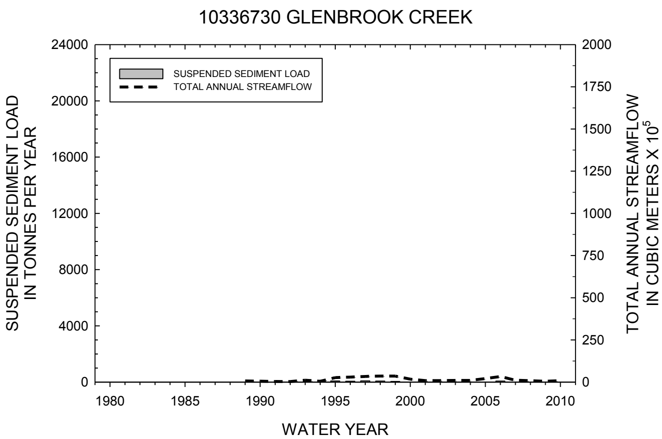
- Rowe, T.G. 2000. Lake Tahoe Interagency Monitoring Program: Tributary sampling design, sites, and periods of record: U.S. Geological Survey Fact Sheet FS-138-00, 4p., available online at http://pubs.er.usgs.gov/usgspubs/fs/fs13800.

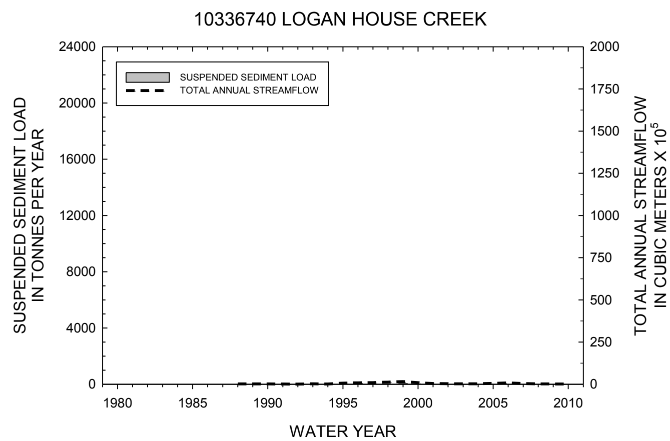
- Boughton, C.J., Rowe, T.G., Allander, K.K. and Robledo, A.R., 1997, Stream and Ground-Water Monitoring Program, Lake Tahoe Basin, Nevada and California: U.S. Geological Survey Fact Sheet FS 100-97, 6 p., available online at http://pubs.er.usgs.gov/usgspubs/fs/fs10097.

Figure 1. Suspended sediment load (in metric tonnes per year) for each of the five regularly monitored streams in Nevada. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near the tributary mouth.









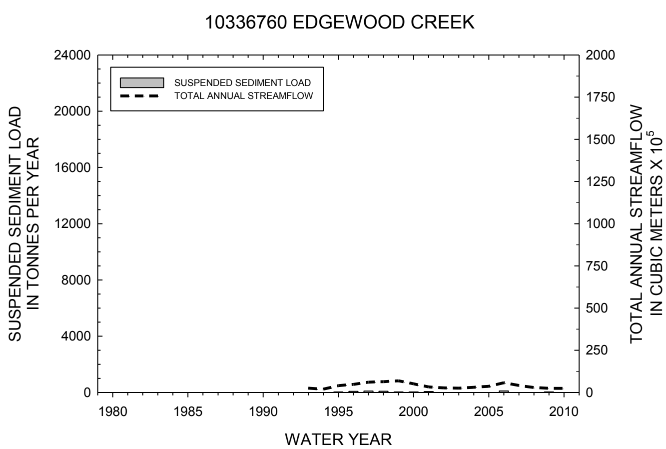


Figure 2. Suspended sediment load (in metric tonnes per year) for each of the five regularly monitored streams in California. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near the tributary mouth.

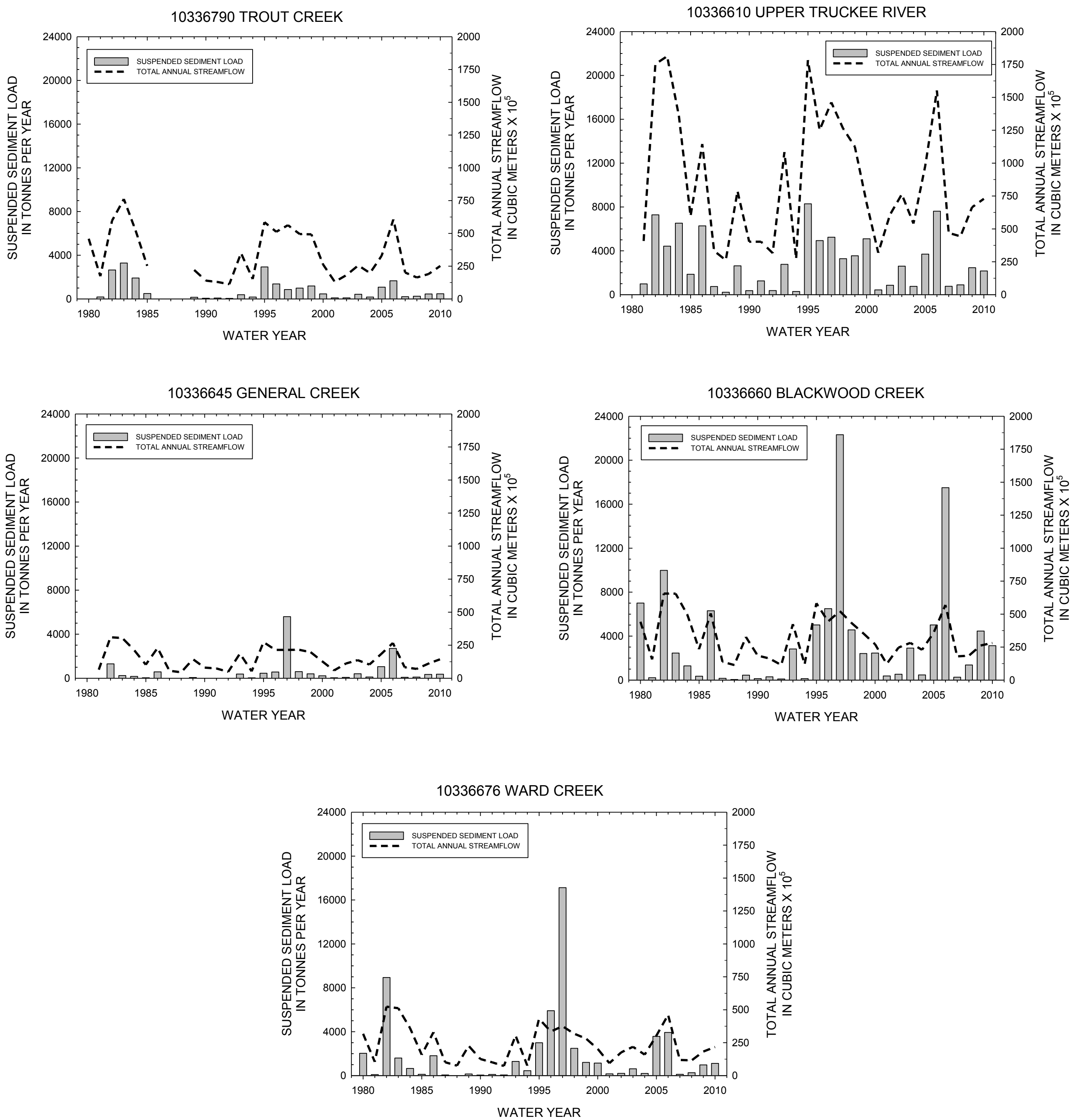
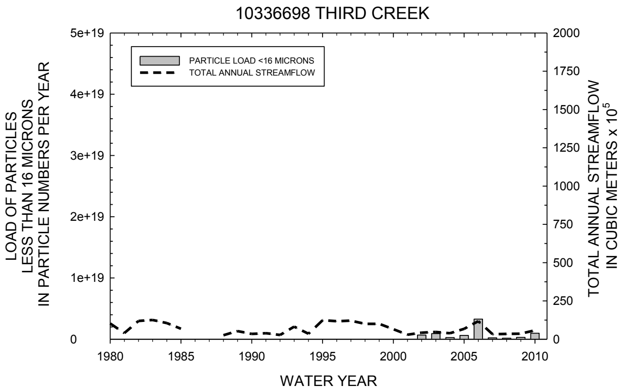
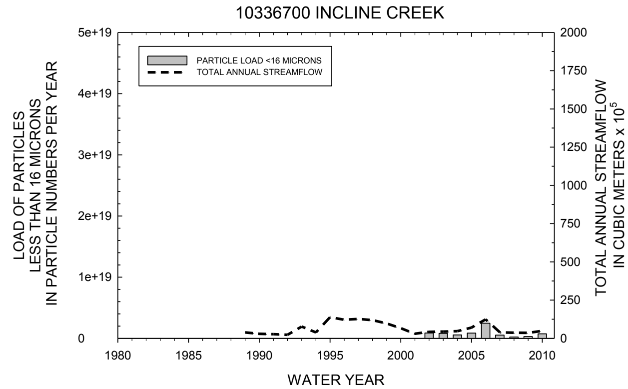
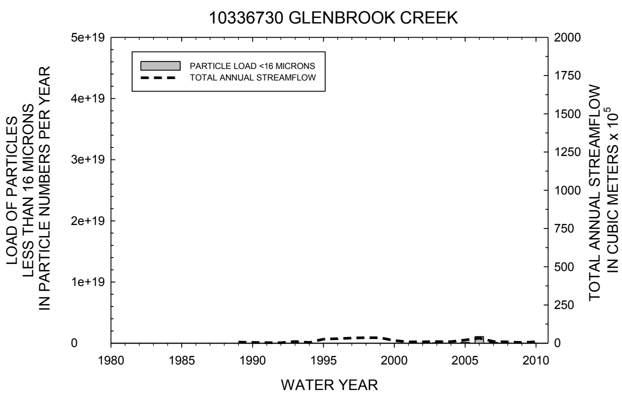
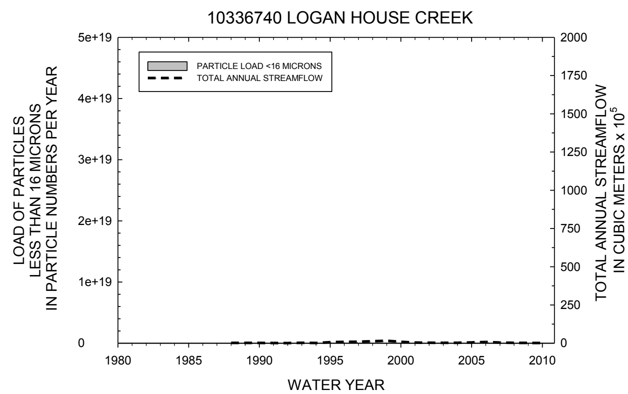


Figure 3. Fine particles less than16 μm in diameter load (expressed as particle numbers per year) for each of the five regularly monitored streams in Nevada. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near the tributary mouth.









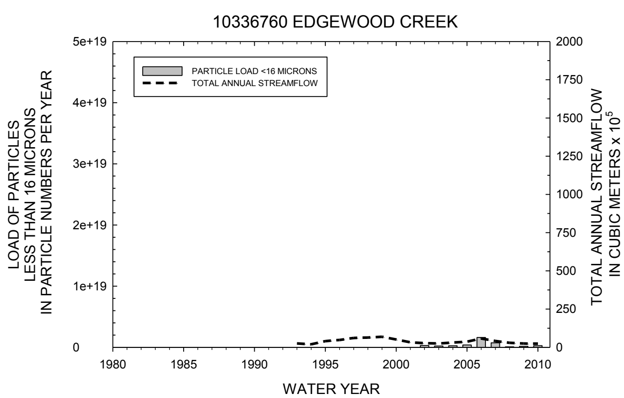
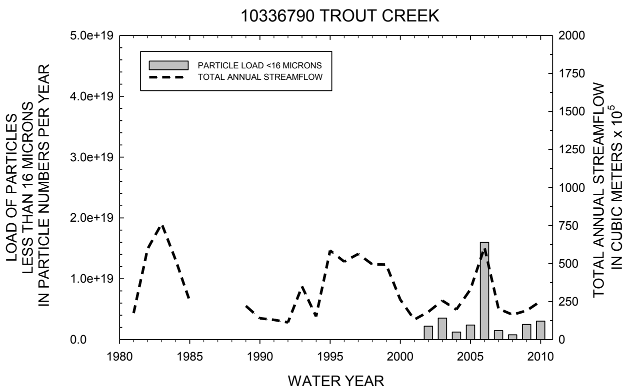
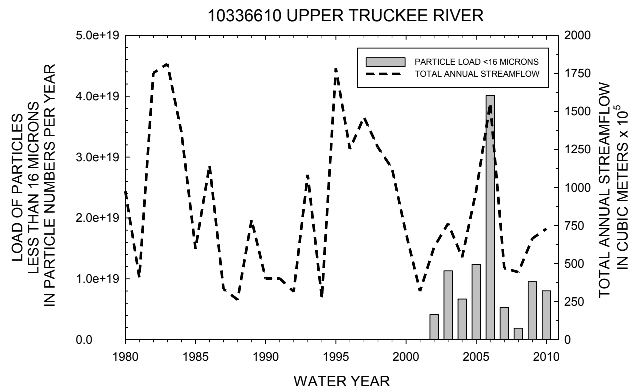
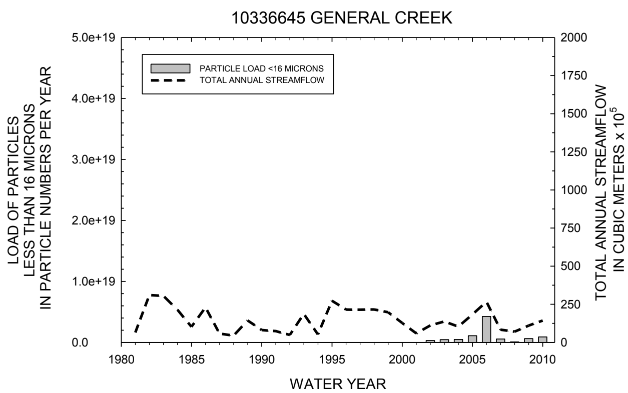
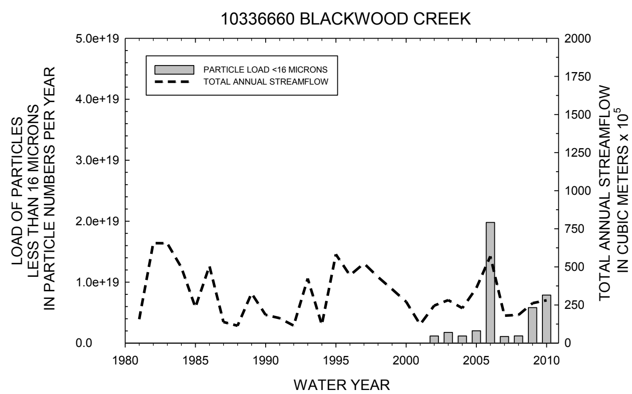


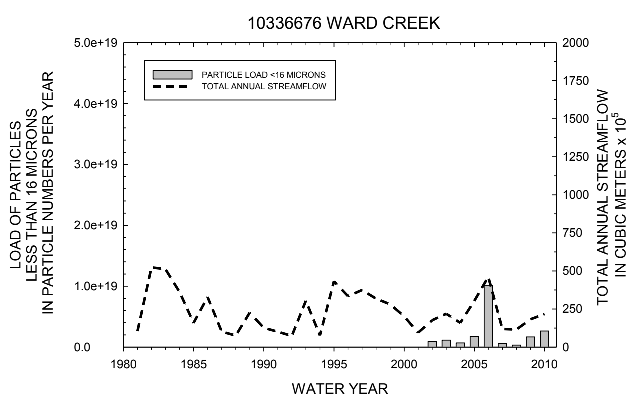
Figure 4. Fine particles less than16 µm in diameter load (expressed as particle numbers per year) for each of the five regularly monitored streams in California. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near the tributary mouth.











Total Phosphorus and Soluble Reactive Phosphorus

Relevance – Phosphorus (P) is a critical nutrient required by all plants. Along with nitrogen (N) these are the two most important elements that limit the growth of algae. Prior to the early-mid 1980s, algae in Lake Tahoe experienced increased growth when either phosphorus or nitrogen were added singularly; however, since the early-mid 1980s algal growth has been primarily enhanced by phosphorus.[1] This fundamental change in algal response has been attributed to excessive nitrogen loading via atmospheric deposition.[2] Today, algal growth is most stimulated when N and P are added in combination—referred to as co-limitation.[3] Since phosphorus is associated with soils, restoration of disturbed land and erosion control will help reduce the input of phosphorus to Lake Tahoe. Phosphorus can be measured in many chemical forms. Lake Tahoe Interagency Monitoring Program (LTIMP) monitors total phosphorus (TP) as well as soluble reactive phosphorus (SRP). SRP provides a first approximation of phosphorus that is bioavailable to algae and bacteria.[4]

Status – For water year (WY) 2010 the yearly TP loads from the ten regularly monitored streams ranged from 5 kilograms per year (kg/yr) at Logan House Creek to 3,817 kg/yr at the Upper Truckee River. The average yearly TP load from all ten regularly streams was 1042 kg/yr (Figures 5 and 6). The yearly SRP loads from the ten regularly monitored streams ranged from 0.89 kg/yr as P at Logan House Creek to 497 kg/yr as P at the Upper Truckee River for WY 2010 (Figures 7 and 8). The average yearly SRP load was 129 kg/yr as P.

Trends – Analysis of trends in hydrology/water quality data can be influenced by the "signal to noise" ratio. In this case the "signal" is the effect of land-use changes and watershed restoration, while the "noise" represents the natural variability in yearly precipitation, rain versus snow, timing of snowmelt and other meteorological factors outside human control, and variability due to errors associated with sampling and laboratory analyses. In the Lake Tahoe Basin, the signal to noise ratio is affected by the high variability in yearly meteorology (i.e. the natural occurrence of very wet, very dry and "average" years).

Water years 1993 through 2010 is the period of focus for the analysis of trends, because monitoring at the tenth stream began in WY 1993. The methods used to calculate loads also were the same for all streams starting in WY 1993. Trends in phosphorus loads are highly influenced by the natural year-to-year variation in precipitation and stream discharge, as observed for yearly suspended sediment (SS) and fine particles less than 16 microns in diameter (PSD) loads. Between WY 1993-2010, the yearly TP loads ranged from 2 kg/yr at Logan House Creek in WY 1994 to 15,887 kg/yr at Blackwood Creek in WY1997.

The averages of the yearly TP loads in the individual LTIMP streams over the 18-year period of record ranged from 15 to 3,988 kg/yr (Table 3).

Table 3. Average yearly total phosphorus loads from WY 1993 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average yearly total phosphorus load (kg/yr)	Percent contribution
Upper Truckee	3,988	31%
Blackwood	3,315	26%
Ward	2,160	17%
Trout	1,478	11%
Third	726	6%
Incline	561	4%
General	454	3%
Edgewood	172	1%
Glenbrook	110	1%
Logan House	15	<1%

Nevada streams Edgewood, Glenbrook, Logan House, and Incline creeks, and General creek in California have had consistently low TP loads over the entire period of record. Peaks in yearly TP load are usually in association with high water years. This is particularly evident for the streams along the west side of Lake Tahoe such as Blackwood and Ward creeks where yearly inflow and TP load rise and fall in unison. TP loads were high during WY 1997 in Blackwood and Ward creeks; and high in WY 2006 in Blackwood Creek. This same pattern was observed for SS loads and is expected, as phosphorus is geochemically associated with the surface of sediment particles. In both WY 1997 and 2006 TP load in Blackwood Creek exceeded the Upper Truckee River even though yearly inflow was less. This resulted from the severe rain-on-snow events that flushed sediment and phosphorus from the watershed in those higher water years. It is notable that the TP load from General Creek was low during water years 1997 and 2006 despite peaks in SS. Compared with the Upper Truckee River, Trout Creek has less TP load and muted peaks. As seen for SS loading, Third Creek exhibited higher TP loads in the early-mid 1990s, with load (and inflow) remaining lower since WY 2001. The restoration of Rosewood Creek caused a change in hydrology and possibly water quality in Third Creek. The Rosewood Creek channel was restored two to three times, and most recently in 2003 with the goal of reducing the amount of SS delivered to Third Creek. Before 2003, Rosewood Creek entered Third Creek just below Highway 28, upstream of the gauge and sampling location. During the most recent restoration, the stream was re-routed and now enters downstream of the Third Creek gauge and sampling site. The loss of the Rosewood Creek input at the sampling site likely contributed to the reduced loads and total flow in Third Creek.

Between water years 1993-2010, the yearly SRP loads ranged from 0.32 kg/yr as P at Logan House Creek in WY 1994 to 1,116 kg/yr as P at Upper Truckee River in WY 1995 (Figures 7 and 8).

The averages of the yearly SRP loads in the ten regularly monitored streams over the 18-year period of record ranged from 2 to 496 kg/yr as P (Table 4).

Table 4. Average yearly soluble reactive phosphorus loads from WY 1993 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average yearly total soluble reactive phosphorus load (kg/yr) as phosphorus	Percent contribution
Upper Truckee	496	35%
Trout	302	22%
Ward	163	12%
Blackwood	147	11%
Incline	86	6%
General	67	5%
Third	62	4%
Edgewood	46	3%
Glenbrook	28	2%
Logan House	2	<1%

The relationship between yearly inflow and SRP load was very good for each stream and reflective of the similar year-to-year yearly flow-weighted concentrations. Along with SS and dissolved nitrate plus nitrite (see below), SRP load data is available since the early 1980s when regular monitoring began for some of the streams. There are no obvious signs of substantial changes in the relationship between yearly inflow and SRP load over time (therefore no important trend relative to factors besides inflow). SRP loads did not show the large spikes in WY 1997 and 2006 as seen for TP for Blackwood and Ward creeks. Most phosphorus enters the stream as TP adsorbed onto sediment particles. By means of the phosphate buffer mechanism a chemical equilibrium is typically established between TP and SRP in the water.[5] However, it is hypothesized that there may not be sufficient time for such an equilibrium to establish under high flow conditions, given the steep slopes in the Basin and the resulting rapid time-of-travel to the Lake.

Confidence – There is high confidence in the reliability of the data used to calculate yearly loads as the data collection consistently followed national field monitoring protocols established by the U.S. Geological Survey for stream monitoring.[6,7] All field and laboratory data are subject to extensive quality assurance requirements.[8] A total of 20-35 individual samples are collected each water year from each of the ten streams. This sampling frequency is considered sufficient to sample during different inflow conditions observed during the water year. The stream monitoring program focuses on both event-based conditions (large runoff events associated with rainfall and snowmelt) and baseline conditions (low inflow during summer when precipitation is negligible). The analytical methods for measuring sediment, fine particles, and nutrients has been developed and customized for use in aquatic systems where concentrations can be extremely low.[9]

Human and Environmental Drivers – The Lake Tahoe TMDL found that on average, and over the period 1994-2004, the yearly load of TP from all sources was about 46 metric tonnes (1 MT = 1000 kg or 2,205 lbs), with about 26 percent coming from non-urban upland runoff and stream channel erosion.[10] The Basin-wide SRP load was about 13 metric tonnes with 26 percent coming from non-urban upland runoff and stream channel erosion. The input of soils from land disturbance in the watershed, either via surface runoff or transport of dust to the Lake, is the major source of this nutrient.

Monitoring Approach – The LTIMP stream monitoring program was first developed in 1979 to provide a Basin-wide evaluation of sediment and nutrient input from streams to Lake Tahoe and to support research efforts to better understand the drivers affecting the clarity of Lake Tahoe. Ten streams have been monitored since the early 1990s; five in California (Upper Truckee River and Trout, General, Blackwood and Ward Creeks) and five in Nevada (Third, Incline, Glenbrook, Logan House, and Edgewood Creeks). Six of these streams have been monitored since water year 1980: Upper Truckee River, and Trout, General, Blackwood, Ward, and Third Creeks. Some of the 10 streams have had multiple monitoring stations along the tributary and all have primary monitoring stations at or near the point of stream discharge to Lake Tahoe. A total of 20-35 individual samples are collected each water year from each of the monitoring stations. The ten primary stations allow for the evaluation of the cumulative conditions within the watershed and represent the inputs of suspended sediment and nutrients into Lake Tahoe. U.S. Geological Survey gauging stations are located at each of the monitoring stations, where inflow (discharge) measurements are completed and continuous inflow is calculated and available. Other water quality-related constituents monitored include water and air temperature, pH, specific conductance, and dissolved oxygen. Fine particle monitoring began in 2002 in support of the TMDL.

Monitoring Partners – U.S. Geological Survey – Nevada and California Water Science Centers, University of California at Davis – Tahoe Environmental Research Center, Tahoe Regional Planning Agency, and U.S. Forest Service – Lake Tahoe Basin Management Unit.

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1. Goldman, C.R., A.D. Jassby and S.H. Hackley. 1993. Decadal, Interyearly, and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. Can. J. Fish. Aquat. Sci. 50(7):1489-1496.

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5. Froelich, P.N. 1988. Kinetic control of dissolved phosphate in natural rivers and estuaries: A primer on the phosphate buffer mechanism. Limnol. Oceanogr. 33:649-668.

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http://pubs.water.usgs.gov/twri9A.

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10. Lake Tahoe Total Maximum Daily Load Technical Report. June 2010. California Regional Water Quality Control Board, Lahontan Region, Nevada Division of Environmental Protection.

Additional Information and References:
Following are examples of additional scientific papers, technical reports and agency report that utilize LTIMP data for phosphorus:

- Hatch L., J. Reuter and C. Goldman. 2001. Stream phosphorus transport in the Lake Tahoe basin, 1989-1996. Environmental Monitoring and Assessment 69:63-83.
- Rowe, T. G., Saleh, D. K., Watkins, S. A., and Kratzer, C. R. 2002. Streamflow and water-quality data for selected watersheds in the Lake Tahoe Basin, California and Nevada, through September 1998: U.S. Geological Survey Water-Resources Investigations Report 02-4030, 118 p., available online at http://pubs.er.usgs.gov/usgspubs/wri/wri024030.
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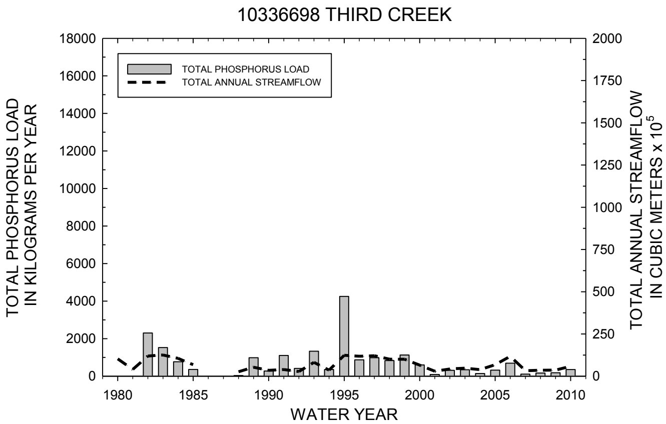
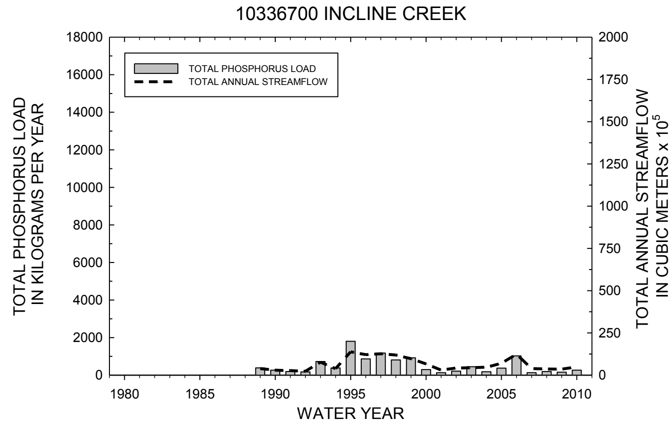
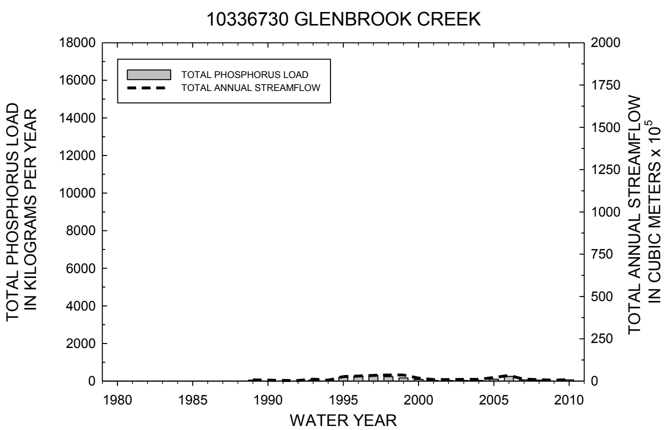
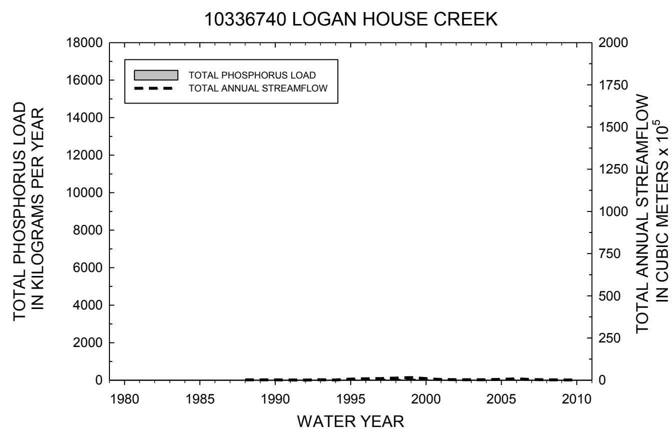
Figure 5. Total phosphorus load (in kilograms per year) for each of five regularly monitored streams in Nevada. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.









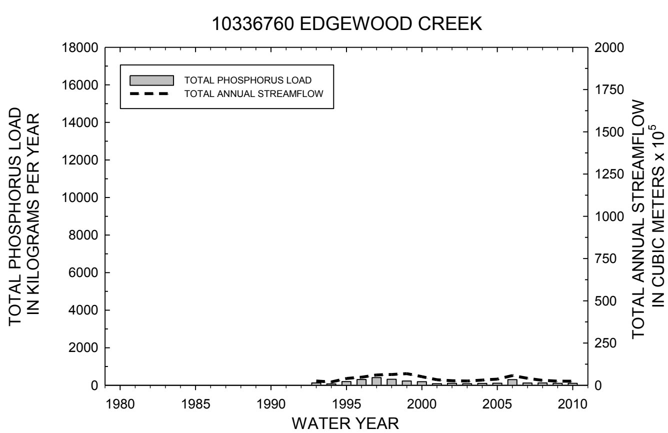


Figure 6. Total phosphorus load (in kilograms per year) for each of five regularly monitored streams in California. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.

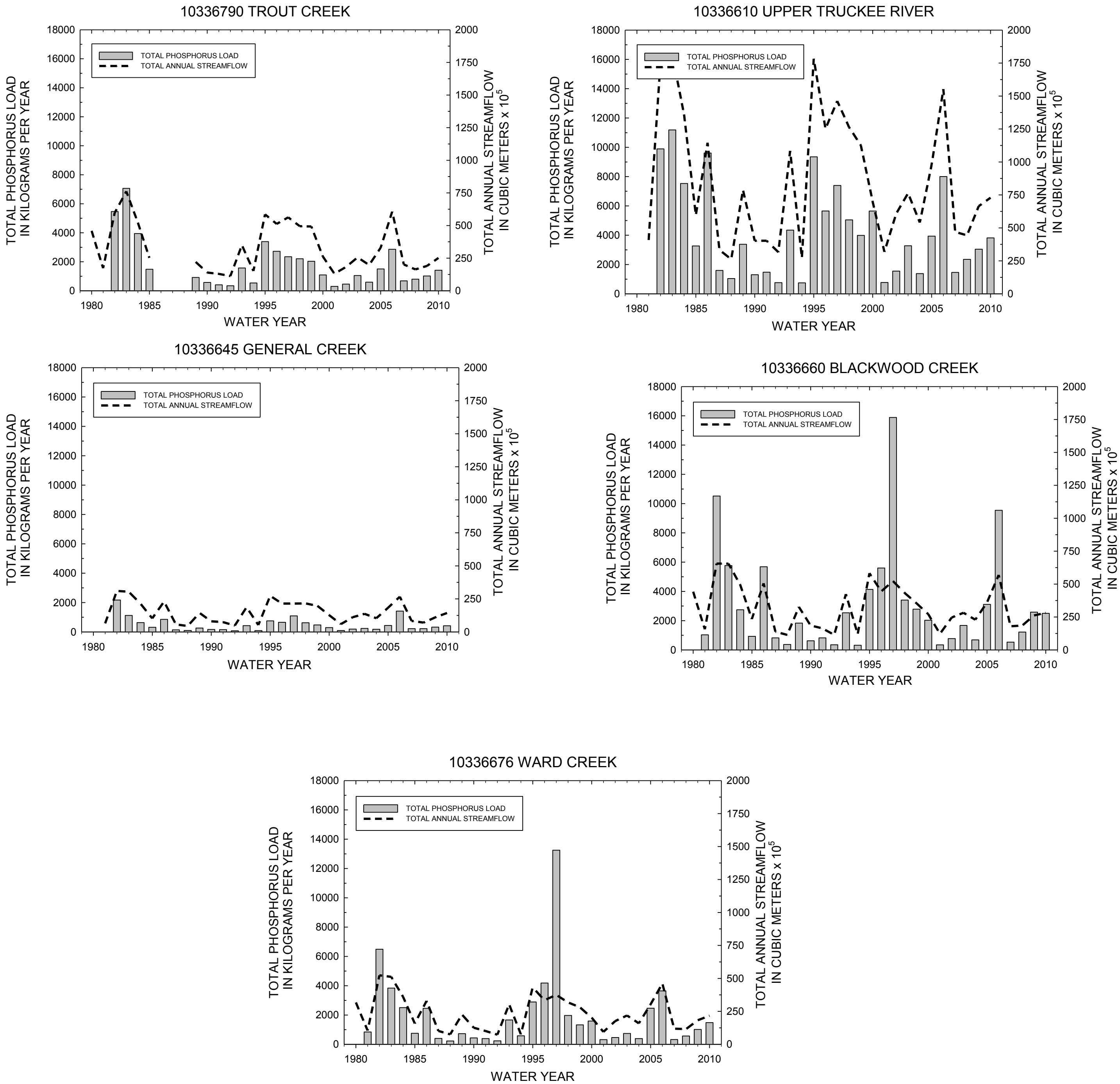


Figure 7. Soluble reactive phosphorus load (in kilograms of phosphorus per year) for each of the five regularly monitored streams in Nevada. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.

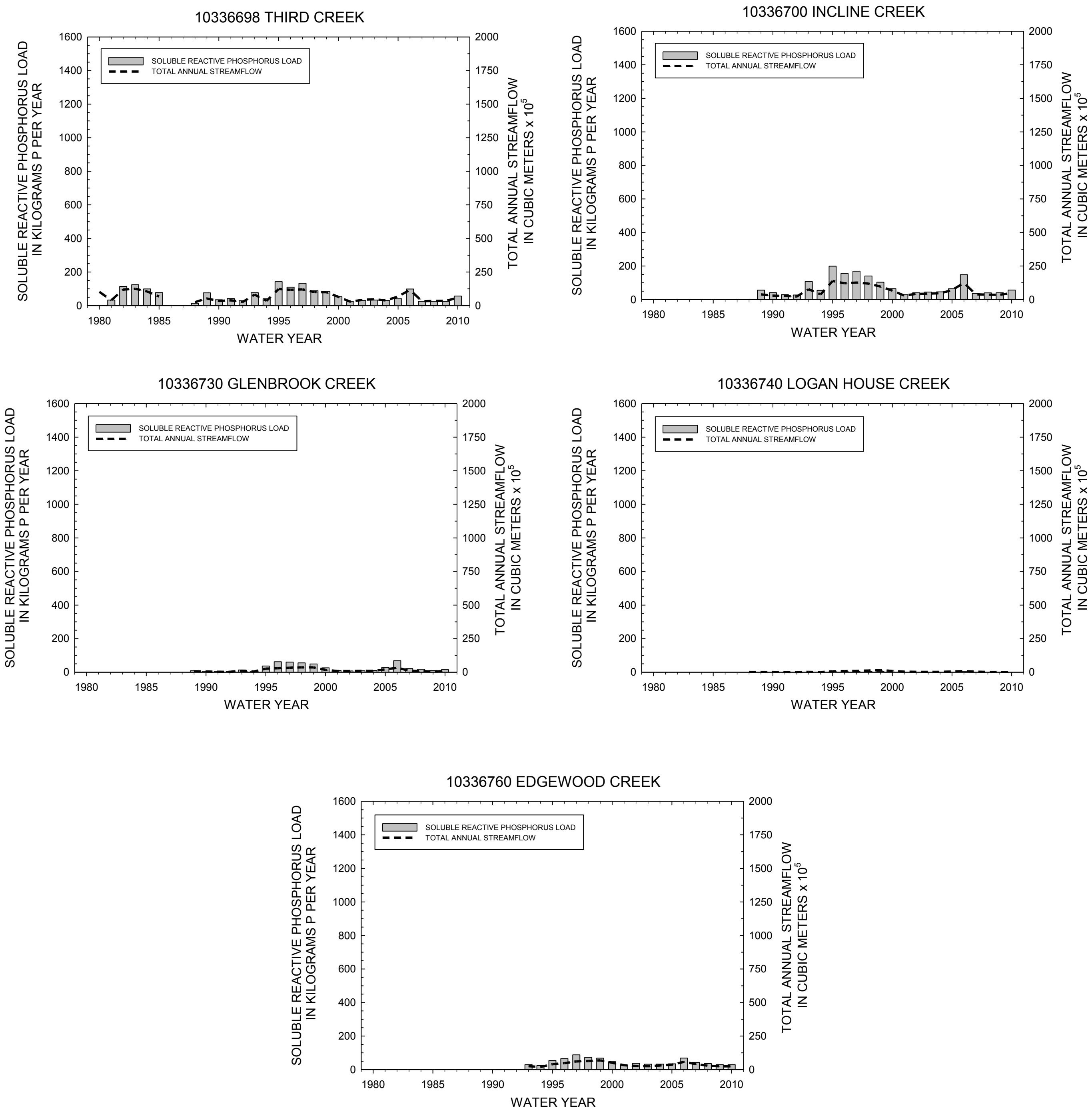
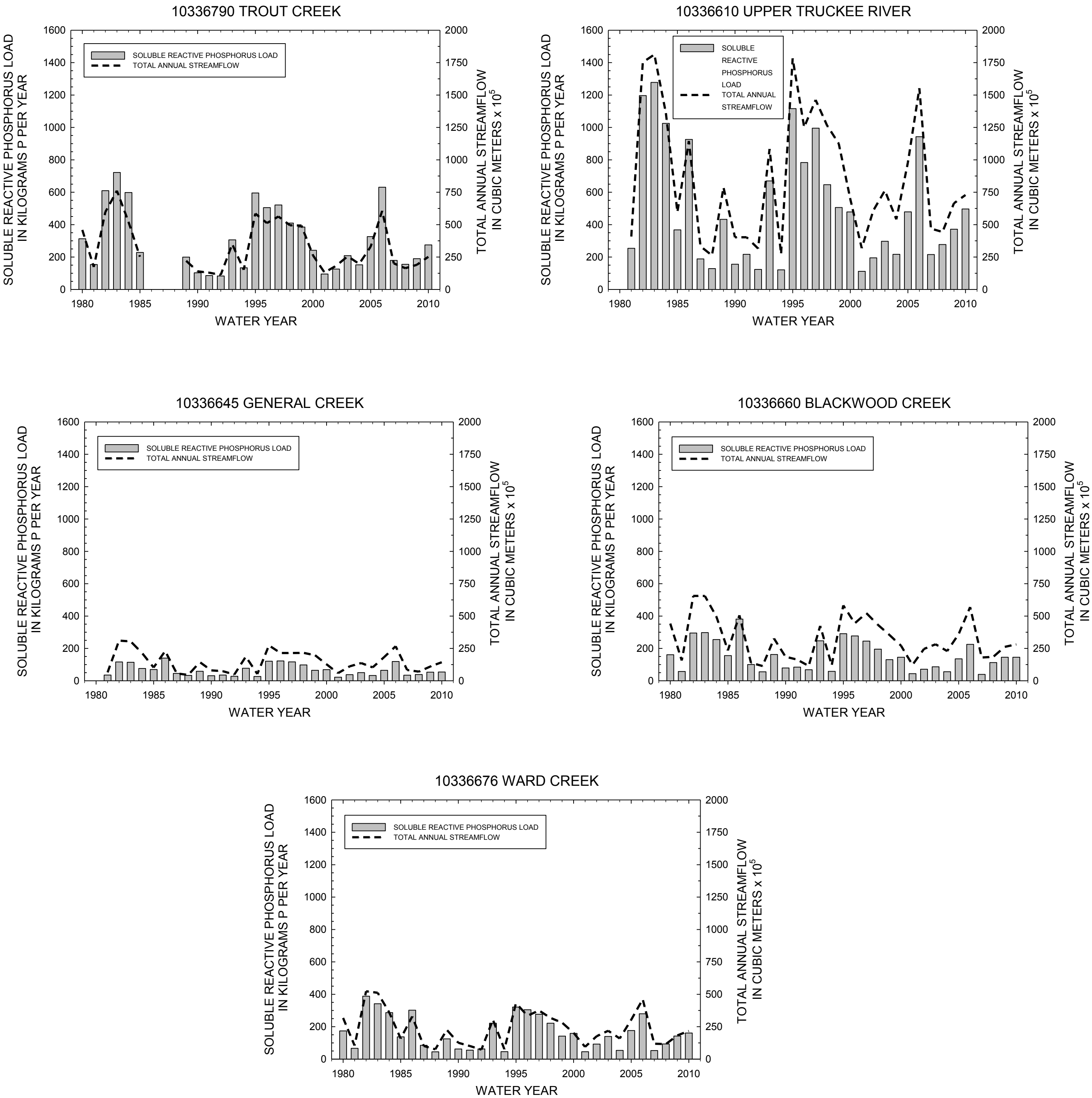


Figure 8. Soluble reactive phosphorus load (in kilograms of phosphorus per year) for each of the five regularly monitored streams in California. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.



Total Nitrogen and Nitrate plus Nitrite

Relevance – Nitrogen is a critical nutrient required by all plants. When added together with phosphorus, algae in Lake Tahoe significantly respond to nitrogen. Stimulation of algal growth by nitrogen alone can occur but it is less frequent.[1] Because nitrogen can occur in gaseous and aerosol forms, and because of its presence in engine and wood combustion products, atmospheric sources of nitrogen are important in the Lake Tahoe Basin. Studies indicate that approximately 55 percent of the total nitrogen and 75 percent of the dissolved inorganic nitrogen that enters Lake Tahoe comes from atmospheric deposition directly to the lake surface.[2] Dissolved inorganic nitrogen (DIN) is the sum of dissolved nitrate plus nitrite and ammonium. Both nitrate and nitrite are readily available to algae. Total nitrogen includes DIN and organic nitrogen (TON). TON is made up of particulate organic nitrogen as well as dissolved organic nitrogen (DON). The ratio of TON to DIN in Lake Tahoe tributaries[3] is on the order of 10:1; however, the bioavailability of DON in aquatic ecosystems is largely under-reported in the scientific literature. Typically, on the order of 80-85 percent of the DIN occurs as nitrate.[3] Since the period of record for nitrate loads in Tahoe Basin streams is longer than for ammonium, and consequently DIN, nitrate plus nitrite loads are used in the evaluation of status and trends.

Status – For water year 2010 the yearly TN loads from the ten regularly monitored streams ranged from 102 kilograms per year (kg/yr) at Logan House Creek to 19,593 kg/yr at the Upper Truckee River (Figures 9 and 10). The average yearly TN load from all ten streams was 5,388 kg/yr. The yearly nitrate loads from the ten regularly monitored streams ranged from 9 kg/yr as nitrogen (N) at Logan House Creek to 1,689 kg/yr as N at Blackwood Creek for water year 2010 (Figures 11 and 12). The average yearly nitrate load was 511 kg/yr as N.

Trends – Analysis of trends in hydrology/water quality data can be influenced by the “signal to noise” ratio. In this case the “signal” is the effect of land-use changes, and watershed restoration projects, while the “noise” represents the natural variability in yearly precipitation, rain versus snow, timing of snowmelt and other meteorological factors outside human control, atmospheric dynamics affecting deposition rates, and variability due to errors associated with sampling and laboratory analyses. In the Lake Tahoe Basin, the signal to noise ratio is affected by the high variability in yearly meteorology (i.e. the natural occurrence of very wet, very dry and “average” years of precipitation and runoff).

Water years (WY) 1993 through 2010 is the period of focus for the analysis of trends, because monitoring at the tenth stream began in WY 1993. The methods used to calculate loads also were the same for all streams starting in WY 1993. Between WY 1993-2010, the yearly TN loads ranged from 23 kg/yr at Logan House Creek in water year 1994 to 58,108 kg/yr at the Upper Truckee River in water year 1995 (Figures 9 and 10).

The average yearly TN loads in the ten regularly monitored streams over the 18-year period of record ranged from 160 to 21,443 kg/yr (Table 5).

Table 5. Average yearly total nitrogen loads from WY 1993 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average yearly total nitrogen load (kg/yr)	Percent contribution
Upper Truckee	21,443	39%
Blackwood	10,110	19%
Trout	7,712	14%
Ward	5,647	10%
General	3,038	6%
Third	2,670	5%
Incline	2,441	4%
Edgewood	879	2%
Glenbrook	460	1%
Logan House	160	(<1%

TN load from the East Shore streams Glenbrook, Logan House, and Edgewood creeks was only about three percent of the combined yearly loads from all ten streams. Over 50 percent of the TN load came from Upper Truckee River and Trout Creek, the two South Shore streams, compared to 34 percent of TN load contributed by Blackwood, Ward and General creeks, three West Shore streams. Incline and Third creeks were intermediate contributors of TN load. TN load generally followed yearly inflow, but it is noteworthy that the relative TN loads from Blackwood and Ward during water year 1997 were much lower than measured for total phosphorus (TP) in water year 1997. However, the relative magnitude of the peaks for TN and TP at Blackwood were the same in water year 2006. While not identical, the percent contribution of the individual streams was similar for TN and TP (with the noted exception of water year 1997). Dramatic differences in TN loading over the period of record appear to be related to flow.

Between water years 1993-2010, the yearly nitrate loads ranged from 1.7 kg/yr as N at Logan House Creek in water year 1994 to 7,950 kg/yr as N at Upper Truckee River in water year 1995.

The averages of the yearly nitrate loads in the ten regularly monitored streams over the 18-year period of record ranged from 17 to 2,623 kg/yr as N (Table 6).

Table 6. Average yearly nitrate loads from WY 1993 through 2010 for each of the ten regularly monitored streams in the Lake Tahoe Basin. Streams are listed in order of their percent contribution to the average load of all ten streams.

Stream	Average yearly nitrate load (kg/yr)	Percent contribution
Upper Truckee	2,623	40%
Blackwood	1,611	25%
Ward	663	10%
Trout	661	10%
Incline	343	5%
General	273	4%
Third	173	3%
Edgewood	145	2%
Glenbrook	51	<1%
Logan House	17	<1%

The TN to nitrate load ratio was typically on the order of 10:1 as expected. The contribution of ammonium load was low and averaged from 2 to 410 kg/yr for the ten regularly monitored streams. The TN to DIN (nitrate+nitrite+ammonium) load ratio was generally near 10:1 with the exception of the Upper Truckee where it was 5-6:1. Examination of the nitrate data collected prior to 1993 shows that the Upper Truckee is the one stream that indicates a possible change in the load – inflow relationship. During the high flow period of 1982-1986 there appeared to be a greater level of nitrate load per unit flow. This is reflected in the yearly flow-weighted concentration values. Since water year 1995, yearly flow and nitrate are related; however there appears to be less of a load per unit flow.

Confidence – There is high confidence in the reliability of the data used to calculate yearly loads as the data collection consistently followed national field monitoring protocols established by the U.S. Geological Survey for stream monitoring.[4,5] All field and laboratory data are subject to extensive quality assurance requirements.[6] A total of 20-35 individual samples are collected each WY from each of the ten regularly monitored streams. This sampling frequency is considered sufficient to sample during different inflow conditions observed during the WY. The stream monitoring program focuses on both event-based conditions (large runoff events associated with rainfall and snowmelt) and baseline conditions (low inflow during summer when precipitation is negligible). The analytical methods for measuring sediment, fine particles, and nutrients has been developed and customized for use in aquatic systems where concentrations can be extremely low.[7]

Human and Environmental Drivers – The Lake Tahoe TMDL[2] found that on average, the yearly load of TN and DIN from all sources was approximately 400 and 200 MT, respectively (1 MT = 1000 kg or 2,205 lbs). Non-urban upland stream flow and stream channel erosion accounted for about 16 percent of this total for TN and <5 percent of the total for DIN. Atmospheric DIN dominated the TN from this source (65-70 percent) and largely originates from vehicle exhaust and forest fuel combustion[8].

Monitoring Approach – The LTIMP stream monitoring program was first developed in 1979 to provide a Basin-wide evaluation of sediment and nutrient input from streams to Lake Tahoe and to support research efforts to better understand the drivers affecting the clarity of Lake Tahoe. Ten streams have been monitored since the early 1990s; five in California

(Upper Truckee River and Trout, General, Blackwood and Ward creeks), and five in Nevada (Third, Incline, Glenbrook, Logan House, and Edgewood creeks). Six of these streams have been monitored since water year 1980 – Upper Truckee River, and Trout, General, Blackwood, Ward, and Third creeks. Some of the ten streams have had multiple monitoring stations along the tributary and all have primary monitoring stations at or near the point of stream discharge to Lake Tahoe. A total of 20-35 individual samples are collected each water year from each of the monitoring stations. The ten primary stations allow for the evaluation of the cumulative conditions within the watershed and represent the inputs of suspended sediment and nutrients into Lake Tahoe. U.S. Geological Survey gauging stations are located at each of the monitoring stations, where inflow (discharge) measurements are completed and continuous streamflow is calculated and available. Other water quality-related constituents monitored include water and air temperature, pH, specific conductance, and dissolved oxygen. Fine particle monitoring began in 2002 in support of the TMDL.

Monitoring Partners – U.S. Geological Survey – Nevada Water Science Center and California Water Science Center), University of California at Davis – Tahoe Environmental Research Center, Tahoe Regional Planning Agency, and U.S. Forest Service – Lake Tahoe Basin Management Unit.

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1. Hackley, S.H., B.C. Allen, D.A. Hunter and J.E. Reuter. 2008. Lake Tahoe Water Quality Investigations: July 1, 2007- June 30, 2008. Tahoe Environmental Research Center, John Muir Institute for the Environment, University of California, Davis. 67 p.

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8. California Air Resources Board. 2006. Lake Tahoe Atmospheric Deposition Study. Final report. Available at http://www.arb.ca.gov/research/ltads/ltads-report.htm.

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The following are examples of additional scientific papers, technical reports and agency report that utilize LTIMP data for nitrogen:

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- Rowe, T. G.; Saleh, D. K.; Watkins, S. A.; and Kratzer, C. R. 2002. Streamflow and water-quality data for selected watersheds in the Lake Tahoe Basin, California and Nevada, through September 1998: U.S. Geological Survey Water-Resources Investigations Report 02-4030, 118 p.
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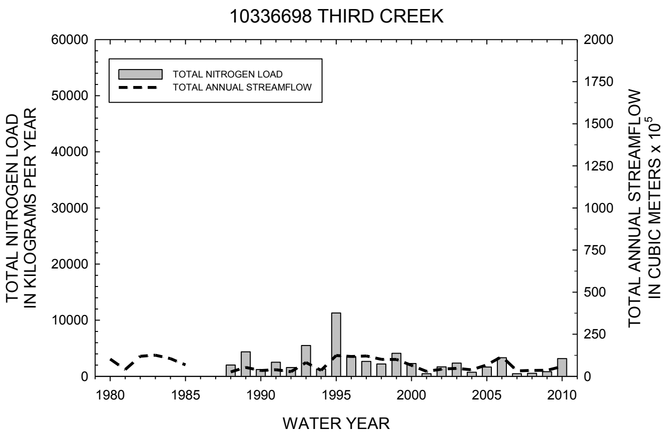
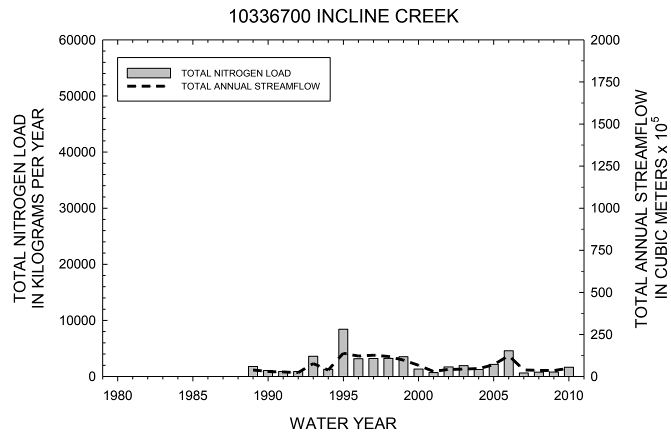
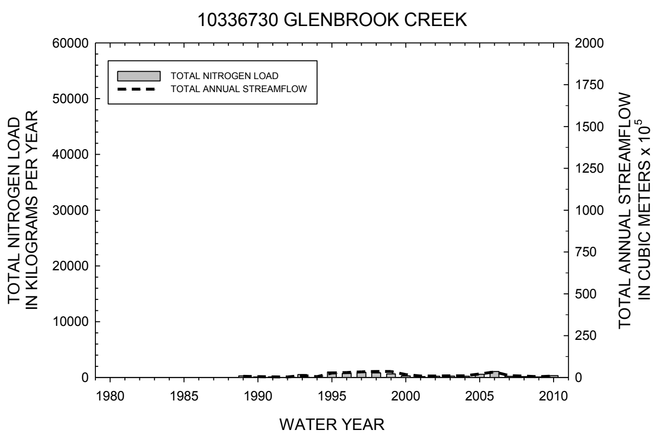
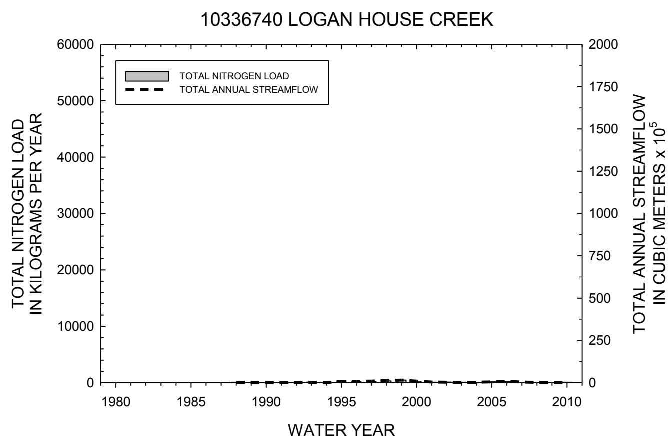
Figure 9. Total nitrogen load (in kilograms per year) for each of the five regularly monitored streams in Nevada. Total nitrogen represents the sum of ammonia, nitrate plus nitrite, dissolved organic-N and particulate organic-N. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.









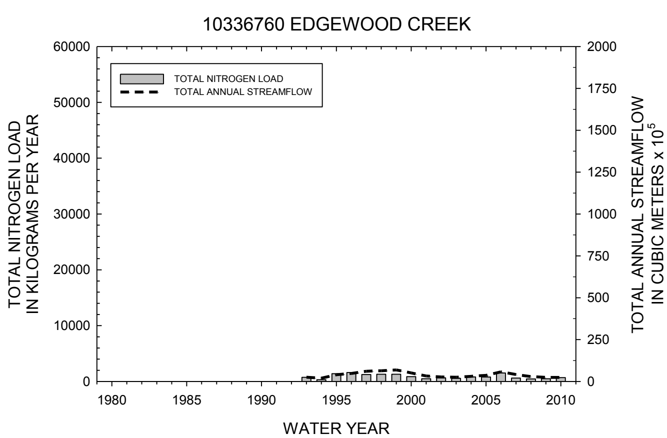


Figure 10. Total nitrogen load (in kilograms per year) for each of the five regularly monitored streams in California. Total nitrogen represents the sum of ammonia, nitrate plus nitrite, dissolved organic-N and particulate organic-N. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.

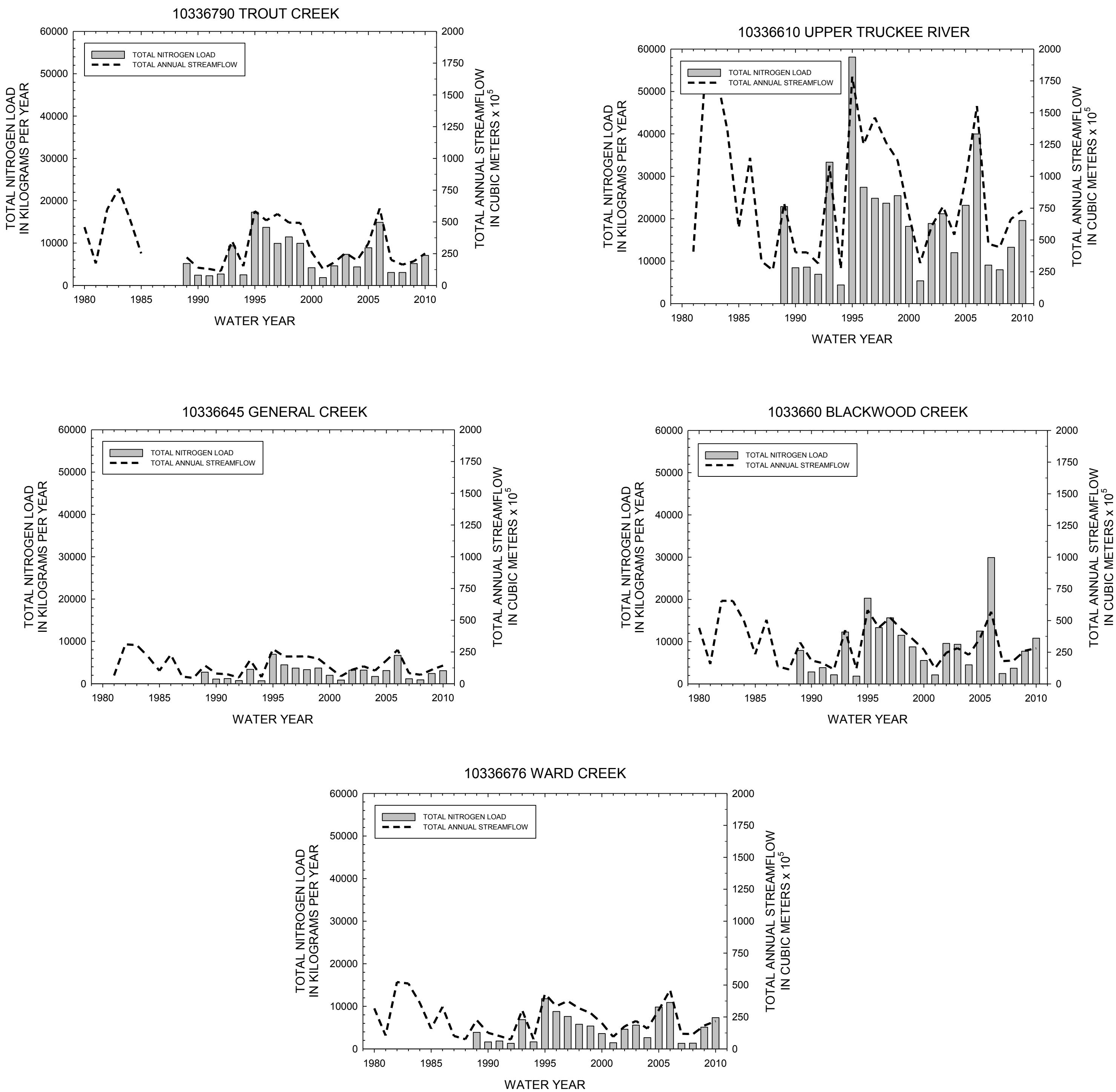
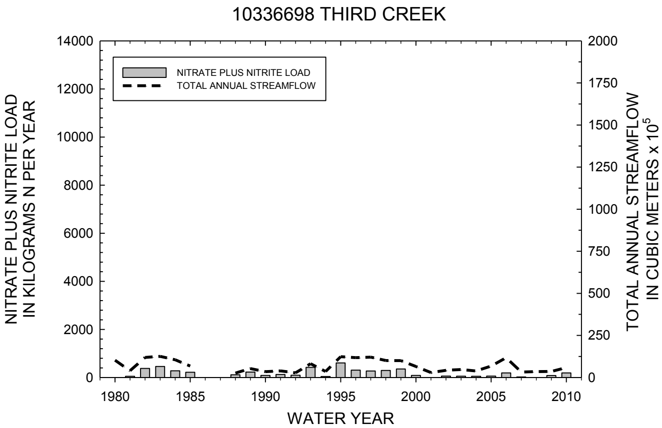
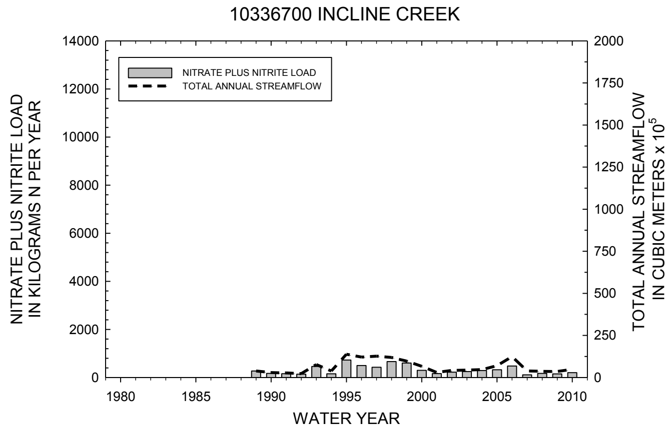
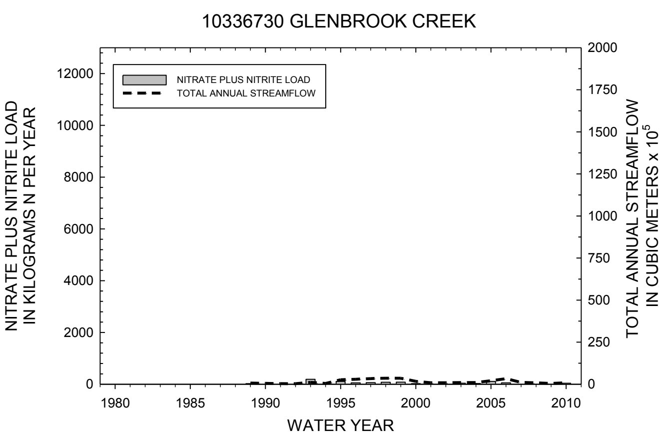
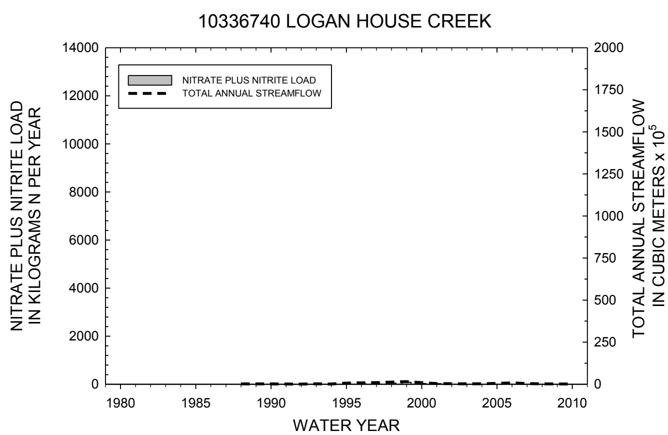


Figure 11. Dissolved nitrate plus nitrite (as nitrogen) load (in kilograms per year) for each of the five regularly monitored streams in Nevada. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.









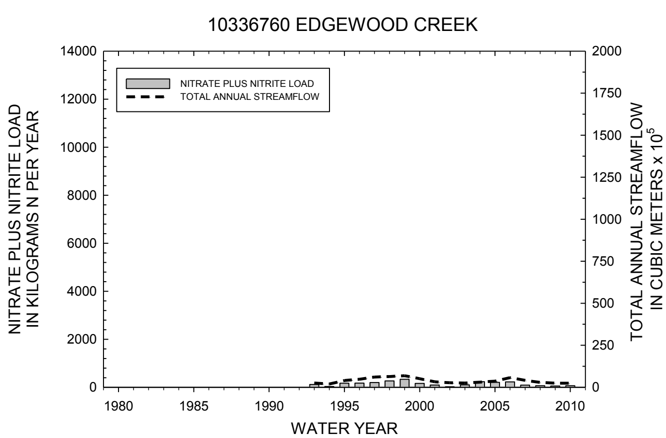


Figure 12. Dissolved nitrate plus nitrite (as nitrogen) load (in kilograms per year) for each of the five regularly monitored streams in California. Data are presented by water year (October 1 - September 30). The dashed line on each plot is the total yearly inflow for the individual stream. Stations are located near tributary mouth.